NOAA Core Project for GAPP:

NCEP-Component

FY02 Accomplishments

and

FY03 Workplan

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Pillar Initiatives of the NOAA Core Project for GAPP

In summary, the main initiatives for the NOAA Core Project for GAPP are:

2.1 - SEASONAL TO ANNUAL CLIMATE PREDICTION AND PREDICTABILITY

-- Propagate/unify Noah LSM in all NCEP global & regional climate & weather models
-- Demonstrate coupled Noah LSM global transferability via NCEP global models
-- Develop/demonstrate a community Eta-based Regional Climate Model
-- Determine global transferability of the community Eta RCM
-- Compare seasonal predictions from coupled global and regional climate models
-- Identify mechanisms and impacts of land-surface on predictability in above

2.2 - WATER RESOURCE APPLICATIONS

-- Support and participate in the Distributed Model Intercomparison Project (DMIP)
-- Develop hydrologic interpretation and application of Ensemble Precipitation Forecasts
-- Participate in field tests of AHPS products in various River Forecast Centers (RFCs)
-- Develop ensemble streamflow forecasts for probabilistic user application
-- Support participation of the Sacramento Model and RFCs in the LDAS project

2.3 - NORTH AMERICAN AND GLOBAL LAND DATA ASSIMILATION SYSTEMS

-- Execute, intercompare, and improve multi- LSMs from multi-institutions
-- Determine transferability of above LSMs from national to global domains
-- Develop and demonstrate the land assimilation of satellite data
-- Intercompare streamflow simulations from 4-6 LSMs over a national domain
-- Act as the major NOAA partner of the joint NASA-NOAA Global LDAS (GLDAS)

2.4 - NOAH LSM IMPROVEMENT INITIATIVES: COUPLED AND UNCOUPLED

-- Improve Noah LSM physics via GAPP, GHP, CEOP, LDAS, PILPS, GSWP, GLASS
-- Advance Noah LSM calibration, joining with GAPP partners and MOPEX
-- demonstrate Noah LSM global transferability via Global LDAS and GSWP-II
-- Support and promote the Noah LSM as a Community LSM

2.5 - SUPPORT/COLLABORATE WITH OTHER GAPP, GEWEX AND WEBS R&D

-- support high resolution regional water and energy cycle studies using operational EDAS, NLDAS, GLDAS, and Regional Reanalysis
-- compare land-surface energy and water budgets of EDAS, NLDAS, GLDAS and Regional and Global Reanalysis

2.6 - TAILOR/QC/ARCHIVE SPECIAL PRODUCTS FOR GAPP, GEWEX AND WEBS

-- Produce/archive Stage IV hourly radar/gage multi-sensor 4-km precipitation analyses
-- Capture hourly/daily operational precipitation obs and ship to GAPP archive at NCAR
-- Archive the forcing/states/fluxes from the North American LDAS (NLDAS)

2.7 – PRODUCE/VALIDATE SATELLITE PRODUCTS FOR GAPP, GEWEX AND LDAS

-- Produce/validate GOES-based surface products (solar insolation and skin temperature)
-- Produce/archive/apply realtime weekly retrievals of global vegetation greenness

NOAA Core Project for GAPP:

NCEP-Component

FY02 Accomplishments and FY03 Work Plan

(Note : See companion PowerPoint file for 11 figures)

1.0 – <u>INTRODUCTION</u>

This document is the annual progress report and work plan for the NCEP component of the 5-year FY01-FY05 GAPP Core Project Proposal of NCEP-OHD-NESDIS. This report also includes a subsection (2.7) for the NESDIS component of the progress report and work plan, by Dan Tarpley. By prior arrangement with GAPP Program Managers, the OHD component of the annual progress report and work plan was submitted earlier in Mar 03 under separate cover by John Schaake.

The budget page and initiatives-summary page provided prior to this introduction present the full budget and span the combined initiatives of the joint NCEP-OHD-NESDIS GAPP Core Project. Section 2 following this introduction is the main-body section, whose sub-section numbers and titles follow those in A) the budget page and initiatives-summary page above and B) the annual report that preceded this one.

The overarching 5-year FY01-FY05 GAPP Core Project Proposal of NCEP-OHD-NESDIS was submitted in February 2001 to NOAA/OGP and to the GAPP Core Project Review Panel convened that year by OGP. This 5-year proposal is an important reference document for the subsequent annual progress reports. The annual progress report and work plan below represents the second in the series of annual reports following the 5-year proposal. For important background and context material, readers are referred to the latter proposal, which is on file in NOAA/OGP and is available from NCEP/EMC upon request (Kenneth.Mitchell@noaa.gov).

The central guideline for the FY01-FY05 GAPP Core Project Proposal was the GAPP Science and Implementation Plan distributed in year 2000. Section 3 of that plan states that the two objectives of the GAPP Program are:

1 - To develop and demonstrate a capability to make reliable <u>monthly to seasonal predictions</u> of precipitation and land-surface hydrological variables through improved understanding and representation of land surface and related hydrometeorological and boundary layer processes <u>in climate prediction models</u>,

2 - Interpret and transfer the results of improved seasonal predictions for the <u>optimal management of water resources.</u>

The FY01-FY05 GAPP Core Project of NCEP, OHD, and NESDIS strives to accomplish both objectives by the following means:

i) internal development and operational implementation within their respective Core Project teams,

ii) science and technology infusion from other collaborating GAPP and GEWEX PIs.

In broad terms, the NCEP component of the Core Project spearheads Objective 1 above, while the OHD component spearheads Objective 2, though both components collaborate with each other and with NESDIS on both objectives.

The overarching GAPP Core Project strategy for seasonal hydrologic prediction, and its incorporation into water resources decision making, follows the "systems" schematic known as the “Shukla Staircase” outlined at the 1998 GCIP “Visions Meeting” (Wheaton, MD).   In our 5-year Core Project Proposal cited above, we augmented the Shukla Staircase to provide the now widely used schematic repeated here in **Fig. 1**, which shows not only the forecast model components of the Shukla staircase but also the crucial, companion data assimilation systems for atmosphere, ocean, and land.

The steps involved in implementing the seasonal prediction suite in **Fig. 1** are:

1) Re-scale and downscale seasonal to inter-annual forecasts of precipitation and surface meteorology (from the continental or regional scale climate prediction models) to the time and space scales required by macroscale hydrologic forecast models;

2) Assimilate observations (e.g. precipitation, surface meteorology, snow cover and water equivalent, streamflow and surface skin temperature) into the land data assimilation systems to estimate initial conditions for land states.

3) Implement hydrologic forecast models in an ensemble mode using ensembles of both the atmospheric forecasts of surface forcing and the land-state initial conditions of the land data assimilation systems.

4) Operate a hydrologic uncertainty post processor to adjust the hydrologic forecasts to account for effects of hydrologic biases and to assure validity of probabilistic forecast information to be used by the water resources decision-makers.

In the context of **Fig. 1**, the GAPP Science Plan and Implementation Strategy, as well as this GAPP Core Project, embrace the role of land-state initialization and land-atmosphere dynamic coupling in seasonal predictability and prediction, both in the warm and cool seasons, to provide a GEWEX land-surface complement to the ocean-atmosphere coupling focus of CLIVAR. The schematic or paradigm in **Fig. 1** can simultaneously provide the means to 1) <u>retrospectively investigate seasonal predictability</u>, and the relative <u>role of land</u> anomalies and land/atmosphere coupling therein, 2) <u>operationally provide realtime seasonal predictions</u> that fully embrace the role of the land surface (as well as ocean and atmosphere) and 3) <u>spatially downscale for meaningful water resource applications</u> via A) imbedded regional climate models and B) either lumped or distributed land/hydrology models.

The infrastructure of **Fig. 1** envisioned here in this Core Project is comprehensive, in that it includes

1 - **land**, **atmosphere**, and **ocean**
2 - **prediction** and 4DDA **assimilation**
3 - **global**, **regional**, and **local**
4 - **coupled** and **uncoupled**
5 - **realtime** (prediction) and **retrospective** (predictability, reanalysis**)**
6 - **ensemble approach** in each prediction component

The circles in the center of **Fig. 1** represent global and regional atmospheric, ocean, and land data assimilation systems to provide initial conditions for the atmosphere, ocean, and land components of the forecast models. The global atmospheric data assimilation is at the very center, representing the backbone of the entire assimilation suite, as it not only initializes the atmospheric component of the global prediction models, but also provides much of the critical surface forcing for the ocean and land data assimilation systems (as well as the lateral boundary conditions for the regional atmospheric data assimilation). The boxes in the corners of **Fig. 1** represent forecast models and the layers of boxes represent an ensemble of model predictions. The layered diamonds represent ensemble forecast output fields that would feed the next higher resolution prediction model component.

To date, members of the ensemble prediction set in **Fig. 1** typically represent model forecasts started from slightly different *atmospheric* initial conditions, but the state-of-the-art in constructing forecast ensembles is rapidly embracing adding a) ensemble members started from slightly different *ocean or land* initial conditions, b) multiple models started from the same initial conditions, or c) multiple physical parameterization schemes (e.g. convection) in a single model. The Core Project is considering strategies for suitable perturbations of land initial states for use in launching ensemble forecast members dependent on uncertainties in land state initial conditions.

One should inspect the prediction model sequence in **Fig. 1** from upper left counter-clockwise to upper right. The upper left represents the global coupled ocean-atmosphere-land forecast model (O-A-L-GCM) providing forecasts at about 100-500 km resolution at forecast ranges of 1-12 months. The global ocean, atmosphere, and land 4DDA systems provide all the initial conditions for this coupled global climate model. Downscaling to successively higher resolution is achieved by successively executing the higher resolution global coupled atmosphere/land model (A-L-GCM) and then the imbedded coupled atmosphere/land regional climate model (A-L-RCM), using the SST predictions of the upper left O-A-L-GMC. Finally, the land-surface forcing outputs of both the GCM and the RCM (especially ensemble QPF) would be used to force the final component at a local scale -- an uncoupled hydrology model (upper right).

All components of the full-bodied seasonal forecast paradigm in **Fig. 1** is envisioned to execute operationally in realtime at NCEP, with operational components of the uncoupled hydrology model also executing at the NWS River Forecast Centers. Only the global model components on the left side of **Fig. 1**, as well as their atmospheric and ocean data assimilation systems already exist at NCEP as a formally operational seasonal forecast system (Ji et al., 1998; Kanamitsu et al., 2002a). The present global atmospheric data assimilation system for the NCEP seasonal prediction system in **Fig. 1** is the realtime extension of the NCEP/DOE Global Reanalysis II (Kanamitsu et al., 2002b). The NCEP ocean data assimilation system (Behringer et al., 1998) presently spans only the Pacific Ocean, but NCEP is presently testing a fully global ocean data assimilation system under the umbrella of the international Global Ocean Data Assimilation Experiment (GODAE). However, the land states of the presently operational NCEP global model components of **Fig. 1** are taken as monthly climatology, from the climatological land states of the NCEP Global Reanalysis 2. Moreover, the presently operational land component of the global systems of **Fig. 1** is the rather old OSU land model of the late 1980's.

All facets of the GAPP Core Project are aimed at i) developing, ii) demonstrating (e.g. the value added), iii) improving and iv) operationally implementing all the additional components of the seasonal forecast paradigm in **Fig. 1** that are not yet formally operational at NCEP (namely components labeled A, B, C, D, E in **Fig. 1**) -- as well as upgrading and unifying the land model throughout all components of **Fig. 1** to the modern Noah LSM. Specifically, these components are:

A) Regional Land 4DDA: North American Land Data Assimilation System (NLDAS)
B) Global Land 4DDA: Global Land Data Assimilation System (GLDAS),
C) Regional Atmospheric 4DDA: Eta-model based atmospheric data assimilation system (EDAS)
D) Regional Coupled Climate Model: Eta-model based Regional Climate Model (Eta-RCM),
E) Regional uncoupled macroscale hydrology model: distributed SAC and Noah land models.

As Sections 2.1, 2.2, and 2.3 below describe, the first two years of the GAPP Core Project have already resulted in hands-on development and testing of components A, D, and E, and intimate involvement with the development and testing of components B and C. Thus working prototypes of components A-E are in hand in the Core Project to date.

The NLDAS and GLDAS components of **Fig. 1** will provide realtime land states, manifesting realtime land state anomalies (soil moisture, snowpack, vegetation state), for the initial conditions of the land component of the global and regional forecast models in **Fig. 1**. The NLDAS and GLDAS systems in the Core Project are being developed, tested and evaluated in partnership with NASA and several crucial GAPP PI partners, including several from the university community (Princeton U., Rutgers U., U. Maryland, U. Washington, U. Oklahoma) and NCEP/CPC. NCEP spearheaded the development of NLDAS, while NASA spearheaded the development of the GLDAS. In FY03, NCEP and NASA are embarking on a concerted effort to transfer a sister GLDAS suite to NCEP, as discussed further in Section 2.3 below.

The Eta-based regional atmospheric data assimilation system for the Eta Regional Climate Model is the Eta-based Regional Reanalysis, and its anticipated realtime extension. The Core Project developed and tested the land and precipitation assimilation components of the Eta-based Regional Reanalysis and has been intimately involved in preparing the GAPP-funded Regional Reanalysis for its 25-year 1979-2003 production phase at NCEP. The realtime extension of the Regional Reanalysis at NCEP would provide the Regional Atmospheric 4DDA of **Fig. 1**

The Core Project developed and is now testing the NCEP Eta-based Regional Climate Model (Eta-RCM). Like the Regional Reanalysis and the NLDAS, the Eta RCM utilizes the most recent version of the Core Project's Noah Land Surface Model (Noah LSM). Moreover, the Eta RCM utilizes all the same physics, resolution (32 km, 45 levels), large horizontal spatial domain (all of North and Central America), and terrain fields and land/sea mask of the Regional Reanalysis. Hence the Core Project set the configuration of the Eta RCM to be completely compatible with the Regional Reanalysis.

Finally the Core Project has developed, tested, and evaluated two versions of a macroscale distributed hydrological model -- one based on the Noah LSM and one based on the Sacramento

Soil Water Accounting Model (SAC). Additionally, streamflow routing models have been developed for application to either of these land models, at either the 1/8th-degree resolution of the NLDAS CONUS domain, or the 4-km resolution "HRAP" grid of the Distributed Model Intercomparison Project (DMIP), in which the Core Project participated with both the Noah and SAC models.

As an analog to using the frozen configuration of the NCEP/DOE Global Reanalysis 2 as the global atmospheric 4DDA component of **Fig. 1**, it is important to use a frozen configuration such as the Regional Reanalysis for the regional atmospheric component of **Fig. 1**. In both cases the Global Reanalysis and the Regional Reanalysis have 25-year retrospective counterparts going back to 1979. These nearly 25-year retrospective analyses, and the retrospective global and regional free-running seasonal ensemble forecast runs that are launched from these retrospective analyses, provide the crucial climatological database from which one can define seasonal predictions in terms of anomalies from the seasonal forecast models' climatology.

In addition to developing, executing, assessing and refining components A-E above for the seasonal forecast suite in **Fig. 1**, the Core Project will also focus on defining and demonstrating the "value added" of each of the downscaling components of **Fig. 1**, relative to the next larger scale parent component.

Finally, last but not least, the Core Project will unify and improve the Noah LSM as the common land model for every land component in the forecast models and assimilation systems in **Fig. 1**. Also, the SAC land model will operate as a second parallel land model in the Regional Land 4DDA (i.e. NLDAS) and the uncoupled distributed hydrology model suite (upper right of **Fig. 1**).

We close our introduction here with a broad summary of how the seasonal prediction paradigm in **Fig. 1** will operate. The ocean, atmosphere, and land data assimilation systems in **Fig. 1** will temporally integrate and continuously cycle forward in time to provide continuously updated ocean, atmosphere, and land initial conditions at intervals of about 6-24 hours. A new seasonal forecast (say 3-12 month forecast length) via the downscaling suite of prediction models in **Fig. 1** (excepting the hydrology model, see next paragraph) would be launched roughly once or twice each day (from the aforementioned daily updates to the ocean, atmosphere, and land initial conditions), providing a 10-30 member ensemble of 6-12 month forecasts at the end of each month.

Last but far from least, the water resource initiative of Sec. 2.2 is developing and demonstrating a "post-processor" to provide probabilistic QPF to the hydrology model in the upper right of **Fig. 1**, from the 10-30 member ensemble of seasonal atmospheric forecasts. This is a critical endeavor, as the post-processor for probabilistic QPF must account for four traditional problems in long-lead QPF forecasts, namely 1) significant bias, 2) lack of sufficient spread among the ensemble set, 3) lack of extreme events, and 4) insufficient temporal intermittency. This is a major challenge for the hydrology and water resource community, including the Extended Streamflow Prediction (ESP) component of the NWS Advanced Hydrologic Prediction System (AHPS) and its associated National Hydrologic Long-rang Prediction System (NHLPS). This is a key subject of Core Project initiatives in Sec. 2.2.

It must be pointed out here that, ultimately, the state of the art in data assimilation for ocean, atmosphere, and land may advance to the point where 4DDA, like the O-A-L-GCM, will be a coupled 4DDA system of ocean-land-atmosphere. However, at the present time, substantial biases in the surface fluxes at the ocean-atmosphere interface (e.g. wind stress, surface heat flux) or the land-atmosphere interface (e.g. precipitation, solar insolation) have required that the ocean and land 4DDA be executed as quasi stand-alone systems, wherein so-called "flux corrections" are applied to the external input surface forcings from the atmospheric 4DDA.

The modeling and 4DDA community has advanced to the point where we are on the threshold of making the paradigm of **Fig. 1** a feasible reality. The pathfinder initiatives already accomplished by GEWEX programs (GCIP, GAPP, GAPP/GCIP Core Project, ISLSCP, GSWP, PILPS) in the area of land modeling, land atmosphere coupling, land data assimilation, and regional climate modeling, together with the companion ocean modeling and ocean 4DDA pathfinder initiatives of the TOGA, CLIVAR and GODAE programs, have provided all the pilot components to assemble and demonstrate an integrated, end-to-end, downscaling, ocean-land-atmosphere seasonal prediction system, such as that depicted in **Fig. 1**. In the realtime prediction setting, this 4DDA/forecast system would execute on a timeframe akin to a daily basis, producing say one 6-12 month seasonal forecast each day, yielding of order 30-member ensembles of 6-12 month forecasts per month.

Over the course of the 5-year FY01-FY05 GAPP Core Project, the Core Project will focus on the land and regional/local downscaling components of Fig. 1. Specifically, the Core Project will:

A) - For realtime application: **develop, demonstrate, and strive to operationally implement**

1) all the land model and land 4DDA components in **Fig. 1** in the NCEP Seasonal Prediction System, including the land model component of all global and regional climate models.

2) develop, demonstrate, and then implement a probabilistic prediction interface between the ensemble seasonal atmospheric forecasts and the hydrology model for water resource application

B) - In retrospective studies: demonstrate the value added to predictability in **Fig. 1** by

1) improved land modeling (physics, parameters, land characteristics) and land-state 4DDA/initialization

2) downscaling with existing and emerging NCEP Regional Climate Models (e.g. Eta)

3) locally-calibrated lumped catchment models versus a-priori regionally calibrated distributed model for hydrology

We re-emphasize that a fundamental role of the Core Project is to partner and collaborate with the research community to provide an operational pathway for the infusion of research into operations. One such operational pathway is our realtime NLDAS project in Sec. 2.3, where we host four land models in parallel. By definition, we recognize that the development and pre-implementation demonstration activities cited above will necessarily involve some benchmark retrospective studies in the Core Project. Nevertheless, we assert here that the role of this Core Project is not to embark on a comprehensive suite of predictability studies to answer a set of research questions. The latter is the role of the grant-supported research PIs in the GAPP Program. Rather, the emphasis here in the GAPP Core Project will be to apply land surface and hydrology models and realtime observation streams accessible by NCEP and OHD to construct and demonstrate components of **Fig. 1** that are viable in the operational and computer settings and of NCEP and the NWS.

Section 2 below will describe the work accomplished over the previous year and the work plan and tasks for the next year in the GAPP Core Project. The organization and agency authorship of the subsections of Section 2 follows that given in the budget page provided prior to the Introduction. The period denoted as "FY02" below designates the 12 months following the FY02 funding increment received by the Core Project in March 2002.

2.0 PREVIOUS YEAR WORK ACCOMPLISHED AND NEXT YEAR WORK PLAN

2.1 SEASONAL CLIMATE PREDICTION AND PREDICTABILITY EMC

2.1.1 Assess the Noah LSM and land memory in the NCEP Global Forecast System EMC

Backround:

The NCEP global Seasonal Forecast Model (SFM) for seasonal-to-annual climate prediction and the global model of NCEP's Global Forecast System (GFS) for medium-range weather prediction diverged from a common "ancestor" NCEP global prediction model in the early 1990's. The NCEP global SFM model was implemented operationally in 2001, in NCEP's operational Dynamical Seasonal Forecast System (Kanamitsu et al., 2002a). NCEP has formally announced that the next generation of NCEP's seasonal forecast model will be unified (in common) with the global model of NCEP's GFS. Henceforth then, the future development of NCEP's global seasonal forecast model and NCEP's medium-range weather forecast model will take place in tandem in the same unified global model, now uniformily designated in NCEP as the GFS. The propagation of the latest version of the Core Project's Noah LSM into the NCEP global predicition model by the Core Project has taken place in the unified NCEP global model of the GFS, which represents NCEP's next generation seasonal forecast climate model.

FY02 Accomplishments

1 - Pursued and completed the inter-agency coordination and memorandums that culminated in the implementation of daily NCEP realtime acquistion of the land states and fluxes of the USAF global land data assimilation system (known as AGRMET) from the Air Force Weather Agency (AFWA) via the NOAA-DOD Shared Processing Network (SPN). Provided scientific and technical support to AFWA's implementation of the latest Noah LSM version from the Core Project.

Discussion:

Later below we describe the recent inclusion and testing of the latest Noah LSM version in the unified global prediction model of the NCEP GFS. The proper assessment of a new land model, and its full potential for land-memory impact, in any global or regional model requires obtaining "spun-up" initial land states that are products of a land data assimilation system employing the same land model as the global or regional prediction model. The USAF AGRMET system of AFWA is the only known global land data assimilation system that operates in a formally operational 24/7 status using non-model gage- and satellite-based precipitation and solar insolation forcing. Most importantly for NCEP and the Core Project, the USAF has chosen the Core Project's Noah LSM as the operational land model of the AFWA AGRMET system.

2 - Tested the Noah LSM in the NCEP unified global model via three-member ensemble forecasts out to 3.5 months spanning summer 2002 (JJA) from three initial states separated by one day in mid-May 2002. The ensemble forecasts were conducted in three modes: A) a control mode using the operational (older) OSU LSM from operational NCEP global land states (which employ nudging to a soil moisture climatology to control drift), B) a test mode using the new Noah LSM from operational NCEP global land states, and C) a second test mode using the new Noah LSM from the USAF AGRMET land states.

Discussion and results:

In the annual report prior to the present one, the Core Project had completed the inclusion of the Noah LSM into the NCEP unified global model, but had accomplished only medium-range forecast tests (forecast lengths of up to two weeks). In the most recent year, the Core Project accomplished its first seasonal prediction tests of the NCEP global model with Noah LSM.

Fig. 2 shows the ensemble-mean forecast over CONUS of the monthly total precipitation (mm) for July 2002 for the three global model test modes described above. Also shown (top right panel) is the observed monthly precipitation (CONUS only) from the gage-based, GAPP-funded CPC analysis of Shi/Higgins (Shi et al., 2003). The control case A (top left panel) shows the now well-known NCEP global model bias of too much convective precipitation in summer in the eastern half of the CONUS. The Noah test case B (lower left panel) shows a marked reduction of this bias. The Noah test case C (lower right panel) shows notably more improvement still in this bias over that of case B and clearly provides the closest agreement of the three cases with the observed precipitation pattern (except immediately west of Lake Superior).

FY03 Work Plan

1 - The seasonal forecasts tests of the NCEP global model with the Noah LSM will be carried out for the summer of 2003. Together with the summer 2002 results above, the Core Project will examine the ability of these seasonal forecasts to capture the inter-annual variability in the CONUS precipitation patterns between the two years. The summer of 2002 was one of the most widespread episodes of drought in the U.S. since the 1930's dust bowl period.

2 - The above NCEP global tests with Noah were conducted on seasonal prediction time scales. During the next year, the global model tests with Noah will be extended to fully one-year annual cycles and beyond. The purpose of the latter tests will be to establish that the NCEP global model with Noah achieves a reasonable atmospheric climatology when executed in the multi-year mode that characterizes the well-known 20+ year AMIP-style simulations.

3 - As a land-memory impact study, the Core Project will act as the NCEP global model participant in the GEWEX/GLASS sponsored global model land-coupling experiment known as GLACE (Global Land-Atmosphere Coupling Experiment). In this experiment, each participating agency or

group will execute 16 members of their global coupled land/atmosphere model over the 3-month summer period Jun-Aug 1994. These 16 members will act as the control ensemble. Then, as an experimental ensemble, these 16 members will be re-executed wherein the time series of the global land states will be pre-determined from ONE of the members of the control ensemble. The two groups of ensembles will be examined to quantify to what extent removing the land-state coupling freedom reduces the spread/diversity in the seasonal precipitation forecasts among the 16 members.

2.1.2 Test GLDAS-based Noah land states in the NCEP Global Forecast System EMC

Backround:

The Core Project experience with test mode C in Section 2.1.1, using Noah-based AGRMET initial land states, encountered obstacles owing to the different grid , terrain height fields, and soil/vegetation parameters used in the Noah executions of the AGRMET system. Noah land physics include the freeze-thaw processes of soil ice. The higher resolution terrain height field of the AGRMET system felt a different surface air temperature forcing than did the smooth terrain height field in the NCEP global model. Hence the AGRMET soil ice state is not in equilibrium with the surface air temperatures experienced in the NCEP global model. This grid resolution difference also caused a mismatch in the soil/vegetation parameters, and hence soil moisture states, of the AGRMET system versus the NCEP global model. Thus, it became clear that the optimum way to obtain initial land states that are compatible with the land model, resolution, and terrain field of the global prediction model is to execute a land data assimilation system with the same land model on the same grid and same terrain height field employing the same soil and vegetation parameters as the subsequent global prediction model.

FY02 Work Accomplished

1 - The Core Project laid the groundwork with its GLDAS NASA partner (leads Paul Houser and Matt Rodell) to transfer the GLDAS system of NASA to NCEP computer platforms to execute the Noah land model in GLDAS configuration and infrastructure executing at NCEP on NCEP computers. As preliminary steps, the Core Project hired a new NCEP GAPP team member (Dr. Helin Wei) to undertake the task of transferring and executing the NASA GLDAS system on NCEP computers. Dr. Wei began learning the configuration of the NASA GLDAS system and the grid and land parameter fields for the Noah land model as utilized in the NCEP global prediction model. He leveraged and extended the surface forcing software suite of the NCEP NLDAS to the global domain and produced sample NCEP-derived global surface forcing sets on the exact grid of the NCEP global model for use in the NCEP global model configuration of the GLDAS.

Substantial additional work accomplished by the Core Project on GLDAS with its NASA partner is presented in the LDAS section of Section 2.3. The work described in the above paragraph is the specific GLDAS work related to executing GLDAS using the same Noah model physics, Noah model parameters, and grid and terrain fields as that employed in the NCEP global forecast model.

FY03 Work Plan

1 - In addition to global model seasonal forecast test modes A, B, C described in Section 2.1.1, a fourth test mode (D) will be instituted in the next year. Test mode D will use initial land states derived from the Noah LSM cycling on the same grid, with the same surface fields of soil and

vegetation parameters, terrain heights, and global land mask as in the subsequent NCEP global model prediction runs. These Noah-based initial land states on the same grid as the NCEP global model will be obtained either from executing the Noah LSM in the land component of NCEP's Global Data Assimilation System (GDAS), as a surrogate for doing so in GLDAS, or by executing the Noah LSM in the Core Project's joint venture with NASA in executing the Global Land Data Assimilation System (GLDAS), as described later in Section 2.3.

2.1.3 Demonstrate and improve the Eta Regional Climate Model *EMC*

Backround:

In the prior annual progress report, the Core Project developed NCEP's first Regional Climate Model version (Eta-RCM) of the NCEP Eta model and provided the first test executions of the Eta RCM on seasonal time scales. The Eta-RCM uses the same recent (2001) version of the Eta model as used in the NCEP 25-year Regional Reanalysis (R/R). The Eta-RCM exactly matches the very large R/R domain and resolution (32-km, 45 levels). The Core Project carried out 5-member Eta-RCM ensemble 4-month summer season simulations for two summers (1990, 1991). These executions utilized the classic RCM "simulation mode" utilizing Global Reanalysis fields for the time-dependent lateral boundary conditions and observed SST and sea-ice cover.

FY02 Work Accomplished

1 - Formally executed and submitted a 6-month simulation with the Eta-RCM for the warm season of 1990 (May-Oct) for the NAME Model Intercomparison Project (NAMIP), using NCEP global reanalysis boundary conditions.

2 - The above single-member simulation was the only simulation required by the NAMIP plan. The Core Project executed and evaluated a wide set of additional sensitivity runs (to provide much broader insight into science issues surrounding NAME) as follows:

2a - Five Eta-RCM ensemble members for summer of 1990, to demonstrate that for large-domain RCM executions, it is necessary to run multiple members, despite using reanalysis boundary conditions and observe SST, because the large domains allow sufficient internal dynamical variability as to cause substantial spread among ensemble members.

2b- Repeated 2a, but initialized the members from late May, rather than late April, to quantify the sensitivity of the summer simulated precipitation to the choice of initial spring month. Surprisingly little difference was observed, owing to the use of analyzed lateral boundaries.

2c- Repeated 2b, but for the summer of 1991 and demonstrated that the Eta-RCM was able to capture the essence of the interannual variability in observed precipitation over Northern Mexico.

2d - Repeated some members of 2a, using modified SST fields over the Gulf of California, or initial soil moisture from Global Reanalysis 1 rather than Global Reanalysis 2 as the source of initial land states. All of these choices had notable impacts on the simulated summer precipitation for the ensemble member in which they were varied.

3 - The above Eta RCM executions employed the widespread RCM execution mode known as "simulation", which utilizes observed time-dependent lateral boundary conditions (from global reanalysis) and observed SST and sea-ice cover. As a major step toward true prediction mode, the Core Project constructed and tested the Eta-RCM configuration that utilizes actual predictions of the time-dependent lateral boundary conditions, as provided by NCEP's global model dynamical seasonal predictions.

3a - Six member 4-month Eta-RCM summer season executions spanning Jun-Sep (from late May initial conditions) were carried out using both predicted and analyzed time-dependent lateral boundary conditions for both the summers of 1999 and 2000. The simulations were examined to compare to what extent the forecasts deteriorated from use of predicted versus analyzed lateral boundaries and to examine the ability of the Eta-RCM summer executions to capture inter-annual summer season precipitation variability, both in the case of analyzed and predicted lateral boundary conditions. Sample results are shown in **Fig. 3**, which depicts the July 1999 results for monthly total precipitation (mm) in the top row and the corresponding July 2000 results in the bottom row. The leftmost column shows the gauge-based Shi/Higgins observed monthly precipitation analysis (note the 1999 analysis includes CONUS and Mexico, the 2000 analysis excludes Mexico, as the Mexican gauge data were not available in the Higgins/Shi database after April 2000). The center column shows the ensemble mean Eta-RCM simulation using analyzed lateral boundary conditions, while the rightmost column shows the ensemble mean Eta-RCM quasi-predictions using the predicted lateral boundary conditions (all Eta-RCM runs here used observed SST). The observed precipitation in the left panels show a wet (dry) southwest U.S. in 1999 and 2000, with a corresponding dry (wet) central U.S. in 1999 and 2000. Disappointingly, neither of the Eta-RCM columns significantly hint at this inter-annual signal (possibly some slight hint in the central U.S. in the center column that utilized analyzed lateral boundary conditions). None of the Eta executions in **Fig. 3** utilized optimum initial land states, as the latter were taken from the NCEP Global Reanalysis. Rather, in the FY03 work plan below, we propose to test the much more compatible Noah-based initial land states of the Eta/EDAS/Noah-based Regional Reanalysis, which also utilized the assimilation of observed precipitation to drive the soil moisture states. Additionally, we plan to repeat the Eta-RCM experiments in **Fig. 3** with an alternative convective parameterization scheme and parameter adjustments within the present convection scheme.

FY03 Work Plan

1 - Test alternative convective parameterization schemes in the 1990-1991 NAMIP-related Eta-RCM runs and/or in the inter-annual 1999-2000 runs of **Fig. 3**.

2 - Test Regional Reanalysis initial land states in place of Global Reanalysis initial land states in the 1990-1991 NAMIP-related Eta-RCM runs and/or in the inter-annual 1999-2000 runs of **Fig. 3**.

3 - Test A) climatological and B) predicted SST fields in place of observed SST fields in the inter-annual 1999-2000 runs of **Fig. 3**.

2.1.4 Provide/Support Community Version of Eta Regional Climate Model *EMC*

FY02 Accomplishments

1 - Continued to collaborate with the Center for Ocean Land Atmospheres (COLA) and their independent tests of the Eta-RCM (Eric Altshuler, Mike Fennessy). Participated and presented at Eta-RCM technical meetings at COLA (as well as teleconferences and numerous email exchanges) and presented NCEP Eta-RCM results, insights and testing suggestions to COLA. Maintained COLA remote access to NCEP computers for Eta-RCM purposes. Co-authored the COLA journal-submitted paper entitled "Seasonal Simulations over North America with a GCM and three regional models". The abstract of the latter submitted paper concludes that "Considering both model performance and efficiency, the Eta model appears most favorable among the models considered."

FY03 Work Plan

Background:

Several grant-funded GAPP PIs (Dr. E. Berbery, Dr. S. Yang) have requested the Core Project to provide the GAPP and overall research community with a publicly accessible version of the NCEP Eta Regional Climate Model.

1 - Provide and support a public version of the Eta RCM. Provide source codes and supporting files, such as land surface characteristics, on a public anonymous ftp site at NCEP. Additionally, write and provide a self-guided Eta RCM Execution Tutorial. This tutorial must explain setting up the execution scripts and how to produce the initial conditions for the land and atmospheric states from the NCEP Regional Reanalysis or the NCEP Global Reanalysis, as well as how to produce the time-dependent lateral boundary conditions from the NCEP Global Reanalysis and obtain the SST and sea-ice cover fields.

2 - Based on recently returned reviews, collaborate with COLA on the revisions of their submitted journal paper (cited above) entitled "Seasonal Simulations over North America with a GCM and three regional models".

2.2. <u>WATER RESOURCE APPLICATIONS:</u> OHD

<u>OHD CORE PROJECT COMPONENT</u>

SECTION 2.2 REPRESENTS THE OHD COMPONENT OF THE GAPP CORE PROJECT

THE OHD FY02 PROGRESS REPORT AND FY03 WORK PLAN WAS SUBMITTED EARLIER IN MAR 03 UNDER SEPARATE COVER TO NOAA/OGP by JOHN SCHAAKE of OHD.

2.3 - N. AMERICAN AND GLOBAL LAND DATA ASSIMILATION SYSTEMS EMC

Background:

The NCEP Core Project is developing and executing uncoupled land data assimilation systems (LDAS), wherein the surface forcing fields of precipitation and solar insolation are obtained from observed, non-model sources, such as gage/radar/satellite precipitation and satellite-derived surface solar insolation. Within this uncoupled LDAS setting, we are pursuing both the North American LDAS (NLDAS) with several crucial GAPP PIs external to the Core Project, and the Global LDAS (GLDAS) with our NASA partner and USAF partners, as cited earlier above.

2.3.1 Improve/Apply the North American Land Data Assimilation System (NLDAS) EMC

FY02 Work Accomplished

1 - The **flagship FY02 accomplishment of the NCEP Component of the Core Project** was its leadership of multiple GAPP partners on the completion and publication of a concentrated focused study of the 3-year retrospective execution of the NLDAS using four different land models (Noah, VIC, Mosaic, SAC) executed in parallel for the period 01 October 1996 through 30 September 1999. This intensive concentrated study (Mitchell et al., 2003) resulted in ten NLDAS papers being submitted to the upcoming GCIP Special Issue of JGR. The titles and authors of the ten submitted JGR NLDAS papers are provided at the top of Appendix C. The NLDAS was an outstanding success in bringing together multiple GAPP surface forcing products, GAPP surface validation products, and land surface models into a common multi-year NLDAS demonstration over a very large continental domain (CONUS). Table 1 (see separate page at end of main text) illustrates the wide array of multiple GAPP products that were utilized for various purposes in the NLDAS project.

Figs. 4 and 5 show a sample of the results from the above NLDAS retrospective execution. **Fig. 4** shows the 2-year time series of the monthly mean surface energy fluxes (Net Radiation, ground heat flux G, latent heat flux LE, and sensible heat flux H) averaged over the ARM flux-station observing network across Oklahoma and Kansas. The Noah-model simulated surface fluxes were closest to the observed and showed the least systematic bias. Additionally (not shown here), the Noah land model had the lowest bias among the four NLDAS land models in annual total runoff and surface evaporation over the eastern half of the CONUS. The top half of **Fig. 5** shows the daily time series of basin-mean snow cover, over the domain of four northern NWS River Forecast Centers, from observations (the NESDIS snow cover analysis) and the four NLDAS land models (Noah, VIC, Mosaic, SAC). The bottom half of **Fig. 5** shows the time series of monthly snowmelt, sublimation and albedo over the Northwest River Forecast Center. **Fig. 5** shows that the Noah land model exhibits an early timing bias in seasonal snowmelt, likely due to its rather low albedo in the presence of snow cover. The SAC land model of the OHD component of the Core Project performed well in snowpack processes.

2 - The NCEP component of the Core Project continues to spearhead, lead, and direct the multi-institution realtime and retrospective NLDAS project. The NCEP Core Project coordinates, executes, leads and documents the quasi-monthly NLDAS meetings and telephone conferences. The NCEP Core Project component continues the realtime generation and archive of hourly NLDAS surface forcing now extending over four years from Apr 99 to the present (Apr 03).

3 - Tested the application of the Core Project-developed adjoint model of the Noah land model in "identical twin" experiments to correct soil moisture states via assimilation of land surface skin temperature (LST). These initial experiments were conducted at the GAPP-funded surface flux-observation site of GAPP PI Tilden Meyers for the period of May-June 1998. The Noah model control run at this site utilized the station-observed surface forcing. The intentionally degraded "twin run" utilized arbitrarily and substantially degraded precipitation forcing by imposing a systematic low bias on heavy precipitation amounts. The Noah simulated soil moisture states of this twin experiment were then "corrected", via variational assimilation of the simulated skin temperature from the control run, as illustrated in **Fig. 6**. The LST was only assimilated only over a 3.5-day window in **Fig. 6**, to mimic the expected intermittency (owing to cloud cover) of the availability of satellite-derived IR-based LST.

4 - The NCEP Core Project continues to collect and archive realtime USGS streamflow observations at over 11,000 CONUS basins and applies them in the validation of 4-model NLDAS daily streamflow simulations, which utilizes the Core Project-developed common NLDAS streamflow routing model (Lohmann et al., 2003).

5 - The NCEP Core Project component gave many NLDAS presentations over the past year at AMS conferences, AGU meetings, EGS meetings, GAPP PI meetings, and seminars at HQ NWS, U. Maryland, Penn State U., and LIS, GSWP, and GLASS workshops at COLA. (See Appendix B)

FY03 Work Plan

1 - With the completion of the 3-year NLDAS retrospective cited above, the NCEP Core Project will resume and continue NLDAS realtime executions for the Noah land model.

2 - Identify the data sources and design the execution strategy for a forecast component of the NLDAS, where NCEP ensemble atmospheric forecasts for the short, medium, and seasonal forecast ranges could be employed to provide NLDAS forecasts of surface forcing for execution of the NLDAS land models in forecast mode, including ensemble streamflow forecasts.

3 - Provide realtime NLDAS land states and fluxes to NCAR. NCAR has requested NLDAS land states in realtime from NCEP for the purpose of initializing the land component of realtime executions of NCAR coupled regional forecast models. Participate in the NCAR Land Working Group and contribute NLDAS expertise to this group's present focus of constructing a land-input preprocessor for NCAR coupled regional forecast models.

4 - Acquire and study the forward radiative transfer model of the NASA-NOAA Joint Center for Satellite Data Assimilation and preprare to utilize it as the common forward radiative transfer model in the NLDAS suite, for the purpose of simulating top-of-atmosphere brightness temperatures in preparation for the direct assimilation of satellite observed brightness temperatures.

2.3.2 Improve/Apply the Global Land Data Assimilation System (GLDAS) EMC

FY02 Accomplishments

1 - In preparation for next year's transition from NASA of an NCEP capability to execute the NASA GLDAS infrastructure, the Core Project continued to:

1a - Produce and archive on a daily basis the realtime satellite-derived global fields of hourly 45-km surface solar insolation, which will be one of the two non-model surface forcing fields used in the GLDAS. These global insolation fields are derived from the USAF hourly 45-km World-Wide Merge Cloud Analysis (WWMCA), formerly known as the RTNEPH, received in realtime at NCEP via the NOAA-DOD Shared Processing Network (SPN). The Core Project applies the solar radiation algorithms of the USAF AGRMET model to the WWMCA cloud analyses. An example WWMCA/RTNEPH global cloud analysis and the resulting global surface solar insolation field, valid for 18 GMT on 01 March 2001, is provided in **Fig. 7**.

1b - Further demonstrate, produce and refine the Core Project-spearheaded methodology to temporally disaggregate the NCEP/CPC CMAP/GPCP 5-day global precipitation analysis into 6-hourly intervals using the precipitation output of the 6-hourly NCEP Global Data Assimilation System (GDAS). An example 6-hourly disaggregation of the 5-day "pentad" CMAP global precipitation analysis over the period of June 30 through July 4 is given in **Fig. 8**.

2 - Continue to assist and advise our NASA GLDAS partner on their execution, tests and evaluation of the Noah LSM in the NASA GLDAS, and in the GLDAS ultra-high resolution demonstration experiment (using a 1-5 km global land-mass grid) known as the Land Information System (LIS).

3 - Contribute written sections and figures, as the NCEP Co-author, to the NASA GLDAS paper recently submitted to the Bulletin of the American Meteorological Society (BAMS). This GLDAS BAMS paper includes examples of the Core Project-spearheaded development of global hourly satellite-based surface solar insolation fields for GLDAS (see accomplishment 1 above).

FY03Work Plan

1 - Modify and extend the NLDAS driver to execute the Noah LSM on a global domain on the global Gaussian grid of NCEP's global Dynamical Seasonal Forecast System. Execute this global extension of NLDAS for a 1-4 week sample period using the precipitation and solar insolation forcing cited in 1a and 1b above.

2 - Via collaboration with the NASA GLDAS group, transfer the GLDAS software and supporting data suite of NASA to NCEP and execute the GLDAS at NCEP on NCEP's central computing facility using the Noah LSM over the same grid and test period as in item #1. Demonstrate that the NASA GLDAS configuration can replicate the states and fluxes of the globally extended NLDAS benchmark in #1 above.

3 - Demonstrate that the NASA-transitioned GLDAS at NCEP can be easily configured to execute on the several Gaussian grid resolutions routinely employed by NCEP global models.

2.4 - <u>Noah LSM IMPROVEMENT INITIATIVES: Coupled and Uncoupled</u> (EMC)

FY02 Accomplishments

1 - Formulated and demonstrated in the Noah LSM an improved treatment of the subsurface heat flux under relatively shallow patchy snow cover. This improved treatment included a change to the treatment of the effective thermal conductivity of the snowpack, resulting in an increase of the latter in shallow snowpack states, as illustrated in the left panel of **Fig. 9**. This change reduced the nighttime near-surface cool bias over snow cover in winter in the coupled Eta model, as illustrated in the right panel of **Fig. 9**. Therefore, this new formulation was implemented operationally into the NCEP Eta model suite in the past year.

2 - Wrote and submitted a paper (Ek et al., 2003) to the GCIP Special Issue of JGR documenting and illustrating the positive impact of the comprehensive series of NCEP Noah land model advancements by the Core Project over the past six years in NCEP's operational, coupled, Eta/EDAS forecast model and assimilation suite.

3 - Reduced the early bias in Noah seasonal snowmelt by improving (increasing) the Noah LSM albedo over snowpack. As discussed in Section 2.3.1, the 3-year retrospective NLDAS study illustrated that the Noah LSM manifested an early-timing bias in spring snowmelt. These same NLDAS results pointed to the Noah model's low albedo over snow cover as the likely cause. This early Noah snowmelt bias was also noted in the Noah executions submitted by the Core Project to the PILPS-2d, PILPS-2e and GLASS/Rhone land modeling experiments, as reported in the previous annual report. The Noah snow albedo formulation was improved by reducing the influence of the vegetation cover in the albedo algorithm. **Fig. 10** illustrates the old and new Noah snow albedo, and the old and new snowmelt timing, in the example of the PILPS-2d time series for the winter season of 1971-1972 at the PILPS-2d field site at Valdai, Russia.

4 - Modified the Eta postprocessor for Eta model output to permit routine output of a larger host of land surface related fields, including (among many others) canopy conductance components, frozen soil moisture, snowpack density, and various soil hydraulic properties, such as the saturated hydraulic conductivity and porosity.

FY03 Work Plan

1 - Test a groundwater treatment in the baseflow-runoff component of the Noah model. To date, Noah model streamflow simulations show an overly rapid drop-off in the baseflow or recession component of streamflow, as compared to USGS streamflow observations. This weakness in Noah streamflow behavior stems from the lack of groundwater storage in the Noah model.

2 - Test alternative treatments for surface turbulent exchange in the stable atmospheric surface layer, in order to modestly increase surface turbulence in very stable conditions, such as during the winter nighttime in conditions of weak winds, or during advection of relatively warm air over melting snowpack. The Noah model surface layer treatment tends to manifest a near-surface cool bias under such conditions.

3 - Test an implicit iterative solution of the Noah surface energy balance to achieve strict closure with zero residual. Presently the Noah model utilizes an efficient but approximate linearized (explicit) version of the original nonlinear implicit surface energy balance equation. This linearized treatment usually yields acceptably small residuals in the surface energy balance. However, in special cases, such as the onset of appearance or disappearance of snow cover, or sudden and large

changes in solar insolation owing to abrupt and large changes in cloud cover, the residual in the linearized surface energy balance can be disturbingly large.

4 - Test a patchy snow cover treatment to snow sublimation in the Noah model snowpack physics. Noah tests to date indicate that snow sublimation in the Noah model is too high. The chief cause appears to be that over snow cover, the current Noah physics satisfies all of the daytime evaporative demand from the snowpack water/ice content, even when the snow cover is shallow with exposed patches of bare ground and/or vegetation. The new treatment to be tested will allow a portion of the evaporative demand over shallow snowpack to be met via evaporation from the exposed patches of ground and vegetation.

2.5 - <u>COLLABORATE WITH OTHER GAPP, GEWEX AND WEBS R&D</u> (EMC)

FY02 Accomplishments

1 - Participated extensively in the planning and implementation activities of the CEOP Model Output consortium. Accepted and accomplished an action item from the Sep 02 CEOP meetings at IRI to author the initial working draft of the CEOP Model Output Document. Participated in numerous monthly teleconferences of both the International CEOP Model Output Consortium and the U.S. CEOP Consortium. Initiated the first routine daily ftp transmission by any international NWP center of global model output to the CEOP model output archives at both MPI and NCAR.

2 - Executed and submitted the long-term, multi-year Noah LSM executions for specified central CONUS stream basins, as the NCEP Core Project contribution to the OHD-sponsored Distributed Model Intercomparison Project (DMIP). Participated in and presented at the first DMIP Workshop.

3 - Provided execution guidance and evaluation direction to the 50-year (1949-1998) retrospective NLDAS execution of the Noah land model by GAPP PI Huug Van den Dool of NCEP/CPC.

4 - Executed the lion share of the training and tool-building for the M.S. graduate student performing the geo-statistical evaluation of NLDAS states and fluxes under the GAPP-grant for GAPP PI Venkat Lakshmi. The Core Project hosted the graduate student of V. Lakshmi at NCEP on several occasions of extended training and assistance, including provision of temporary office space and desktop computer terminals. The Core Project co-authored and provided the bulk of the figures for the paper submitted from above study to the GCIP Issue of JGR (Syed et al., 2003).

5- Provided coupled Eta/EDAS fields and analysis and co-authorship for the Water and Energy Budget Study (WEBS) of GAPP PI John Roads (Roads et al., 2003).

6 - Collaborated with, and co-authored the submitted paper based on, the study by GAPP PI Hugo Berbery (Berbery et al., 2003) of the energy and water budgets over the Mississippi Basin from 7 years of the GAPP-sponsored NCAR database of operational coupled Eta/Noah output from NCEP.

7 - Collaborated with the dynamic vegetation model study of GAPP PI Roger Pielke. Co-hosted a visit of Roger Pielke graduate student Curtis Marshall, who is conducting the lion share of modeling tests for this study, including the coupled RAMS/GEMS model and the coupled Eta/Noah model, using initial land states from the Core Project NLDAS suite.

8 - Successfully negotiated with the OU Mesonet group of Ken Crawford to release OU Mesonet data in realtime without charge to the GAPP PIs involved in the Core Project NLDAS endeavor. Hosted a visit to NCEP of members of the OU Mesonet group.

9 - Collaborated with, and co-authored the submitted paper based on, the third in the series of PILPS-2d modeling assessments by GAPP PI Alan Robock and his graduate student Lifeng Luo (Luo et al., 2003).

10 - Presented at, and represented the NCEP Core Project in, the workshop on stable boundary layers by the GEWEX Atmospheric Boundary Layer Study (GABLS).

11 - Presented at, and represented the NCEP Core Project in, the workshop on land-atmosphere interaction by the GEWEX Land-Atmosphere System Study (GLASS).

12 - Served as the land assimilation focal point for the newly launched NASA-NOAA Joint Center for Satellite Data Assimilation (JCSDA). Presented the NLDAS experience and lessons learned to the JCSDA Science Steering Panel meeting at NCEP. Reviewed several land assimilation-oriented proposals submitted to the first JCSDA AO.

FY03 Work Plan

1 - Continue the substantial involvement of the Core Project in supporting the CEOP Model Output consortium. Begin pilot utilization of CEOP Reference Site observations in the assessment of the NCEP global model.

2 - Execute and submit the global 10-year Noah LSM executions to Phase II of the Global Soil Wetness Project (GSWP-II), sponsored by the GLASS component of GEWEX.

3 - Represent NLDAS and GLDAS interests, potential applications, and strategy at the NOAA-NASA Global Reanalysis Renewal Conference at NCAR in Boulder in August 2003.

2.6 – <u>TAILOR/QC/ARCHIVE SPECIAL PRODUCTS FOR GAPP OR GEWEX</u> (EMC)

FY02 Accomplishments

1 - Carried out the following Core Project product archive tasks

1a - Provide Stage IV hourly radar/gage multi-sensor 4-km precipitation analyses to NCAR
1b - Capture hourly/daily precipitation gauge observations and ship to GAPP archive at NCAR
1c - Provide Eta/EDAS operational output to GCIP/GAPP NCAR regional model archive
1d - Archive the surface forcing fields and land states from the national LDAS (NLDAS)
1e - Produce/archive GOES-based surface products as applied to NLDAS
1f - Provide daily ftp of NCEP global model/assimilation output to CEOP model archives at MPI and NCAR

FY03 Work Plan

1 - Continue the archive activities listed in 1a-1f above.

2.7 – PRODUCE/VALIDATE SATELLITE LAND-SURFACE PRODUCTS FOR GAPP

NESDIS CORE PROJECT COMPONENT

THIS NESDIS FY02 PROGRESS REPORT AND FY03 WORK PLAN WAS SUBMITTED BY DAN TARPLEY OF NESDIS/ORA

FY02 Work Accomplished

The major satellite effort during the past year was to use the GOES satellite retrievals of land surface temperature (LST) to validate and compare the land surface models being tested in the NLDAS. The LST is the only large-scale diagnostic variable that can be used to compare and understand the physics behind apparent biases in the models. The work was done by matching GOES and model LST estimates under clear-sky conditions at different times of the day and different seasons for different regions of the CONUS.

Although some preliminary, limited GOES/NLDAS match system work began in the fall of 2001, the current NLDAS match and plot system began full development primarily in early 2002.The skin temperature match verification scatter plots produced at NOAA/NESDIS from this system use matched GOES-East Imager derived GEWEX skin temperature and LDAS model derived skin temperature. The system currently provides web-based match plots and statistics for the NLDAS Noah, MOSAIC and VIC representations using data from a retrospective NCEP NLDAS model and forcing database for years 1998 and 1999. The GOES skin temperature used to make this match (retrieved at 1/2 degree LAT/LON resolution) is also pulled from this database, which has been interpolated to the NLDAS model grid at 1/8 degree LAT/LON (future work includes binning up the NLDAS 1/8 degree LAT/LON skin temperature data to the satellite derived 1/2 degree LAT/LON grid for inter-comparison). The value of this system was proven early in it's development and is twofold. First, it provides for a "ground truth" verification of the various NLDAS derived skin temperature approaches. Second, it has aided in better understanding the impact of the different physics in each of the NLDAS land surface models.

As the system developed, a better understanding of the nature of this data was realized and a considerable amount of time was spent making changes and enhancements to the plots. This enabled a more complete evaluation of the information contained in each plot. The work involved making changes as simple as seasonal adjustments to axis limits or complex as creating quasi-two dimensional color-coded histograms to bring out the underlying signal in plots that contained large numbers of data points. One disadvantage of pulling the GOES derived skin temperature from the NLDAS forcing files is that these files contain no specific GOES channel information. This information was used in the past to filter out known GOES skin temperature biases. Therefore, and alternative statistical approach (using the GOES skin and surface air temperature) was employed to help eliminate biases associated with sub-pixel cumulus and cirrus contaminated retrievals. All plots were generated with and without this screening applied and presented on the web site for review.

An example of the match-ups of the GOES versus NLDAS land-model skin temperature is provided in **Fig. 11**.

In addition to the match portion of the system, a tremendous amount of work focused on re-writing the web staging of this system to allow for easier comparison of the various plots. Due to the large volume of plots available from three different models, all html was re-written to consolidate the plots for all models on one page for a particular month and year. JavaScript was also added to allow for each image to be displayed in separate frames, thereby allowing the user to toggle easily back and forth between images when comparing them. A sample GOES/LDAS plot from this system is attached. All plots from this system can be viewed at:

http://orbit-net.nesdis.noaa.gov/goes/gcip/html/gwxldas.html.

In addition to the GOES/NLDAS match system described above, a parallel GOES/SURFRAD match system was also developed in 2002 to provide for verification of the derived GOES skin temperature. This system makes use of the same NCEP 1/8 degree LAT/LON interpolated GOES skin temperature data (used above) and matches it with a skin temperature derived from the SURFRAD program data archive found at http://www.srrb.noaa.gov/surfrad/surfpage.htm. The SURFRAD skin temperature is derived by applying the Stefan-Boltzmann law to the measured upwelling IR at each station. A sample plot from this system is also attached. All plots from this system can be viewed at:

http://orbit-net.nesdis.noaa.gov/goes/gcip/html/surfrad_gldas/surfrad_goes8thdeg.html.

In early 2003, the entire match and plot processing system was ported to a new platform in preparation for the activation of GOES-12. With the resumption of a new 'research' version of GEWEX to process GOES-12 data, a new SURFRAD match system has also been developed to provide for verification results. Although in the preliminary stage and still undergoing refinement, early results from this system can be viewed at

http://orbit-net.nesdis.noaa.gov/goes/gcip/html/surfmatch_new.html.

FY03 Work Plan

During the next year, work will focus primarily on continued validation of the new GOES-12 GEWEX products. In addition, comparisons of EDAS and NLDAS skin temperature with both the GOES-West imager derived skin temprature and GOES-East sounder derived skin temperature are also planned.

Table 1. GCIP-sponsored products applied by the NLDAS project

A) FOR PRODUCING NLDAS SURFACE FORCING

1) Daily, gage-only, Shi/Higgins precipitation analysis by NCEP/CPC (Shi et al., 2003):
-- A) realtime analysis on 1/8-degree grid (about 6500 observations daily), plus PRIZM application after Feb 2002
-- B) 50-year retrospective on 1/4-degree grid (about 13000 observations daily), with or without PRIZM applied, and added quality control

2) Hourly, GOES-based, 0.50-degree surface insolation (Pinker et al., 2003), plus 25 other products in GEWEX product suite
--- A) by NESDIS: realtime operational production
--- B) by U.Maryland: archived retrospective from Oct 1996 to present, with added quality control

3) Hourly, radar-dominated, 4-km CONUS "Stage IV" precipitation analysis by NCEP/EMC
-- A) realtime analysis, via mosaic of Stage III product from RFCs, with added manual quality control (via RFC analyst)
-- B) archived retrospective via NCEP transmission to UCAR, via mosaic of hourly Stage II product (no manual QC)

4) Improvement in physics of Eta/EDAS analyses of near-surface meteorology, by NCEP/EMC, with transmission to NCAR archive since April 1995.

B) FOR VALIDATING NLDAS SURFACE FORCING

5) OU Mesonet surface meteorology observations
6) NOAA/ARL SURFRAD network of surface solar insolation observations

C) FOR VALIDATING NLDAS LAND MODEL OUTPUT(states/fluxes)

7) Oklahoma/Kansas ARM/CART surface flux stations (DOE, Humes)
8) Oklahoma Mesonet soil moisture/temperature observations (OU and Climate Survey)
9) CONUS-wide GOES-based satellite skin temperatures (NESDIS and U. Maryland)
10) N. Hemisphere NESDIS 23-km daily N.H. snow cover analysis (archive to Jan 97)
(next 3 not sponsored in part by GCIP)
11) Illinois network of 18 soil moisture measuring stations
12) Inter-mountain western U.S. network of SNOTEL observations
13) National network of USGS streamflow observations

D) FOR IMPROVING NLDAS SURFACE CHARACTERISTICS

14) 1-km CONUS soil texture database of Doug Miller of Penn State
15) NESDIS 0.144-degree global monthly NDVI-based vegetation greenness

E) IMPROVED LAND SURFACE MODELS

16) Noah model improvements by NCEP and OHD (and collaborators)
17) VIC model improvements by Princeton U. and U. Washington (and collaborators)
18) SAC model improvements by OHD (and collaborators)
19) Streamflow connectivity network and routing model by NCEP and OHD

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Lohmann, D., K. Mitchell, P. Houser, E. Wood, J. Schaake, A. Robock, B. Cosgrove, J. Sheffield, Q. Duan, L. Luo, R.W. Higgins, R. Pinker, J. D. Tarpley, 2003: Streamflow and Water Balance Intercomparison of Four Land-Surface Models in the North American Land Data Assimilation System (NLDAS), submitted to *J. Geophys. Res.*

Luo, L., A. Robock, and Co-Authors, 2003: Effects of frozen soil on soil temperature, spring infiltration, and runoff: results from the PILPS 2(d) Experiment at Valdai, Russia, *J. Hydrometeor.*, in press.

Mitchell, K., D. Lohmann, P. Houser, E. Wood, J. Schaake, A. Robock, B. Cosgrove, J. Sheffield, Q. Duan, L. Luo, R.W. Higgins, R. Pinker, J. D. Tarpley, D. Lettenmaier , C. Marshall, J. Entin, M. Pan, W. Shi, V. Koren, J. Meng, B. Ramsay, A. Bailey, F. Wen, 2003: The Multi-institution North American Land Data Assimilation System (NLDAS): Utilizing Multiple GCIP Products and Partners in a Continental Distributed Hydrological Modeling System, in preparation for GCIP Special Issue of *J. Geophys. Res.*

Shi, Wei, R. Wayne Higgins, Evgeney Yarosh, 2003: A Unified Raingauge Dataset and Multi-year Daily Precipitation Reanalysis for the United States, submitted to *J. Geophys. Res.*

Syed, H., V. Lakshmi, E. Paleologos, D. Lohmann, and K. Mitchell, 2003: Analysis of spatial scales in land surface hydrological processs, submitted to *J. Geophys. Res*.

(See also the NCEP Core Project yearly publication list in Appendix C)

APPENDIX A: **NCEP Land Team Members**

GAPP Funded:

-- Dag Lohmann: N. American LDAS
-- Cheng-Hsuan (Sarah) Lu: Land-surface modeling in NCEP global prediction model
-- Rongqian Yang: Eta Regional Climate Model
-- Helin Wei: Global LDAS and N. American LDAS
-- Pablo Grunmann: Assimilation of satellite data, Noah adjoint model
-- Sid Katz (1/2-time): precipitation & model output data sets/archives for GAPP, CEOP
-- Fedor Mesinger (1/4-time): Eta Regional Climate Model

EMC Base Funded (non-GAPP)

-- Ken Mitchell (Team Lead)
-- Michael Ek

NASA Funded (non-GAPP)

-- Jesse Meng

JCSDA Funded (non-GAPP)

-- Vince Wong

APPENDIX B: NCEP Core Project Presentations at Conferences/Workshops/Symposia (Previous 12 months)

By Ken Mitchell:

Dept. of Meteorology Seminar, University of Maryland, 25 Apr 02,
"Land Surface and Hydrology Modeling in the NCEP Eta Mesoscale Forecast Model and 4DDA",
oral presentation.

Mississippi River Climate and Hydrology Conference, New Orleans, LA, May 13-17, 2002,
"The Multi-Institution North American Land Data Assimilation System Project: (N-LDAS)",
oral presentation.

Mississippi River Climate and Hydrology Conference, New Orleans, LA, May 13-17, 2002,
"Contributions of the GCIP/GAPP Core Project To NCEP Operational Prediction Models",
oral presentation.

Mississippi River Climate and Hydrology Conference, New Orleans, LA, May 13-17, 2002,
"Weather and Climate Prediction Models in support of NCEP Service Centers, NWS Field Offices,
the Private Sector and the Public", oral presentation.

Weather Research and Forecast (WRF) Model Workshop, NCAR, 25-26 June 2002,
"The Configuration, Physics, and Optimal Initialization of the Unified Noah-OSU Land Surface
Model for WRF", oral presentation.

Global Soil Wetness Project 2 Workshop, Center for Ocean Land Atmosphere: 30 Sep 2002,
"The Multi-Institution North American Land Data Assimilation System Project: (N-LDAS)",
oral presentation.

Department of Meteorology Honorary Tarbell Lecture, Penn State University, 31 October 2002,
"Land Surface and Hydrology Modeling Comes Home to Roost in NCEP Weather and Climate
Prediction Models", oral presentation.

Seminar at Headquarters National Weather Service, 15 January 2003,
"Land-Surface Modeling Takes Root in NCEP Operational Weather and Climate Prediction:
A Decade of Multi-disciplinary Science and Technology Infusion with collaborators in the
GCIP and GAPP Programs of NOAA/OAR/OGP",
oral presentation.

AMS Symposium on Variability of Water in Weather and Climate, AMS Annual Mtg, 14 Feb 03,
"Regional Data Assimilation at NCEP: Recent Advancements in the Assimilation of
Precipitation, Soil Moisture, Clouds, Water Vapor, and Snowpack",
invited talk.

AMS 17th Conference on Hydrology, Long Beach, CA, 9-13 Feb 03, Paper 3.9, "Upgrades to the
Unified Noah Land-Surface Model in the Operational NCEP Mesoscale Eta Model",
oral presentation.

Joint Center for Satellite Data Assimilation Science Steering Committee Meeting, NCEP, 19 Feb 03 "The Multi-Institution North American Land Data Assimilation System Project (NLDAS)", oral presentation.

CEOP Implementation Planning Meeting, MPI, Berlin, Germany, 2-4 April 2003, "Model Output Strategy for CEOP", oral presentation.

CEOP Implementation Planning Meeting, MPI, Berlin, Germany, 2-4 April 2003, "The Multi-institution North American Land Data Assimilation System Project (NLDAS)", oral presentation.

<u>By Dag Lohmann</u>:

D. Lohmann and NLDAS Team, New Orleans: Evaluation of streamflow and Snowpack simulations in the land surface models of the North American Land Data Assimilation System (NLDAS) Project, AMS Mississippi River Conference, May 2002

D. Lohmann and C.Peters-Lidard, Spring AGU 2002, Washington: Changes in the lower Boundary condition of the NOAH land surface model.

D. Lohmann, K. Mitchell, M. Ek, P. Grunman: The NOAH land surface model in Uncoupled experiments (NLDAS, RHONE, DMIP) at NCEP, Second Intergovernmental Conference on Hydrological Modeling, Las Vegas, 2002.

D. Lohmann and K. Mitchell: Regional Land Data Assimilation, CEOP meeting, Washington DC, 2003.

D. Lohmann and NLDAS Team: Evaluation of streamflow and snowpack simulations in the land surface models of the North American Land Data Assimilation System (NLDAS) Project, AMS conference, Long Beach, Feb 2003.

D. Lohmann and NLDAS Team: Overview and validation work of the North American Land Data Assimilation System (NLDAS) Project, EUG/EGS/AGU conference, Nice, France, April 2003.

<u>By Mike Ek</u>**:**

Spring Seminar Series, Univ. Maryland/Dept. Meteorology, College Park, Maryland, 21 March 2002, oral presentation: Coupled land-atmosphere model evaluation and impact of soil moisture on cumulus initiation.

GEWEX Atmospheric Boundary Layer Study (GABLS) workshop on stable boundary layers ECMWF, Reading, England, 25-27 March, 2002 oral presentation: Experience with stable boundary layer parameterization at NCEP.

GEWEX Land-Atmosphere System Study (GLASS) Workshop on Land-atmosphere

Interaction, Royal Netherlands Meteorol. Inst., De Bilt, Netherlands, 19-20 April 2002, oral presentation: Role of soil moisture on atmospheric boundary layer development.

Mississippi River Climate & Hydrology Conference New Orleans, Louisiana, 13-17 May 2002 poster presentation: NCEP Eta Analysis and Forecast System: Land-surface model changes and model performance assessment

WRF land-surface modeling workshop NCAR, Boulder, Colorado, 25-28 June 2002 oral presentation: Noah LSM changes and performance assessment in the NCEP operational mesoscale Eta model.

AMS 15th Symposium on Boundary Layers and Turbulence Wageningen Univ., Wageningen, Netherlands, 15-19 July 2002 oral presentation: Impact of soil moisture on boundary-layer cloud development.

By Rongqian Yang:

Meeting: Mississippi River Climate and Hydrology Conference
Time and Location: May 13-17, 2002, New Orleans, LA
Title: A Seasonal Simulation of Precipitation over North American with the Eta Regional Climate Model.
Authors: Rongqian Yang and Kenneth Mitchell

Meeting: NOAA's 27th Annual Climate Diagnostics and Prediction Workshop
Time and Location: Oct. 21-25, 2002, George Mason Univ., FairFax, VA
Title: The Eta Regional Climate Model: Model Development and Its Sensitivity in NAMAP Experiments to Gulf of California Sea Surface Temperature Treatment.
Authors: Rongqian Yang and Kenneth Mitchell

Meeting: AGU fall meeting
Time and Location: Dec. 6-10, 2002, San Francisco, CA
Title: Seasonal Precipitation Simulations and Predictions over North American with the Eta Regional Climate Model.
Authors: Rongqian Yang and Kenneth Mitchell

Meeting: 83rd AMS Annual Meeting
Time and Location: Feb. 9-13, 2003, Long Beach, CA
Title: Seasonal Precipitation Simulations and Predictions over North America with the Eta Regional Climate Model.
Authors: Rongqian Yang and Kenneth Mitchell

Meeting: 2003-EGS-AGU-EUG Joint Assembly
Time and Location: April 7-11, 2003, Nice, France
Title: Warm Season Precipitation Simulations over North America with the Eta Regional Climate Model
Authors: Rongqian Yang, Kenneth Mitchell, and Fedor Mesinger

By Cheng-Hsuan (Sarah) Lu:

AGU 2002 spring meeting Washington DC
Predictability of soil wetness and near surface temperature based on
NCEP Seasonal Prediction Model hindcasts
Cheng-Hsuan Lu, Masao Kanamitsu, Wesley Ebisuzaki and Jae Schemm
(oral presentation)

27th Annual Climate Diagnostic and Prediction Workshop, VA
The effect of initial soil moisture on seasonal predictions simulated
by the NCEP GCM
Cheng-Hsuan Lu and Kenneth Mitchell
(oral presentation)

AGU 2002 Fall meeting, SF, CA
Assessing the impact of soil moisture initialization on seasonal
predictions
Cheng-Husan Lu and Kenneth Mitchell
(oral presentation)

AMS annual meeting, Long Beach, CA
Assessing the effect of initial soil moisture and use of Noah land model
on seasonal predictions using the NCEP Global Forecast System (GFS)
Cheng-Hsuan Lu, Kenneth Mitchell, Hua-Lu Pan,
Hann-Ming Henry Juang, and Shrinivas Moorthi
(poster presentation)

By Pablo Grunmann:

5th Workshop on Adjoint Applications in Dynamic Meteorology, Bethel PA, 24 Apr 02,
"Data Assimilation with the Adjoint of the Noah Land Surface Model",
poster presentation.

<u>APPENDIX C</u>: NCEP Core Project Journal Publications (Previous 12 months)

(Note: non-NLDAS papers follow after next list.)

Ten NLDAS papers submitted to the GCIP Special Issue of JGR

"The Multi-institution North American Land Data Assimilation System (NLDAS): Utilizing Multiple GCIP Products and Partners in a Continental Distributed Hydrological Modeling System"
Kenneth E. Mitchell, Dag Lohmann, Paul R. Houser, Eric F. Wood, John C. Schaake, Alan Robock, Brian A. Cosgrove, Justin Sheffield, Qingyun Duan, Lifeng Luo, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley, Dennis P. Lettenmaier , Curtis H. Marshall, Jared K. Entin, Ming Pan, Wei Shi, Victor Koren, Jesse Meng, Bruce H. Ramsay, Andrew A. Bailey, Fenghua Wen

"Streamflow and Water Balance Intercomparison of Four Land-Surface Models in the North American Land Data Assimilation System (NLDAS)"
Dag Lohmann, Kenneth E. Mitchell, Paul R. Houser, Eric F. Wood, John C. Schaake, Alan Robock, Brian A. Cosgrove, Justin Sheffield, Qingyun Duan, Lifeng Luo, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley

"Realtime and Retrospective Forcing in the North American Land Data Assimilation System (NLDAS) Project"
Brian A. Cosgrove, Dag Lohmann, Curtis H. Marshall, Kenneth E. Mitchell, Paul R. Houser, Eric F. Wood, John C. Schaake, Alan Robock, Justin Sheffield, Qingyun Duan, Lifeng Luo, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley, J. Meng

"An Intercomparison of Soil Moisture Fields in the North American Land Data Assimilation System (NLDAS)"
John C. Schaake, Qingyun Duan, Kenneth E. Mitchell, Paul R. Houser, Eric F. Wood, Alan Robock, Dag Lohmann, Brian A. Cosgrove, Justin Sheffield, Lifeng Luo, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley

"Land Surface Model Spin-up Behavior in the North American Land Data Assimilation System (NLDAS)"
Brian A. Cosgrove, Kenneth E. Mitchell, Paul R. Houser, Eric F. Wood, John C. Schaake, Alan Robock, Dag Lohmann, Justin Sheffield, Qingyun Duan, Lifeng Luo, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley

"Validation of the North American Land Data Assimilation System (NLDAS) Retrospective Forcing Over the Southern Great Plains"
Lifeng Luo, Alan Robock, Kenneth E. Mitchell, Paul R. Houser, Eric F. Wood, John C. Schaake, Dag Lohmann, Brian A. Cosgrove, Justin Sheffield, Qingyun Duan, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley

"Evaluation of the North American Land Data Assimilation (NLDAS) over the Southern Great Plains during the Warm Season"
Alan Robock, Lifeng Luo, Eric F. Wood, Fenghua Wen, Kenneth E. Mitchell, Paul R. Houser, John C. Schaake, Dag Lohmann, Brian A. Cosgrove, Justin Sheffield, Qingyun Duan, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley, Jeffery B. Basara, and Kenneth C. Crawford

"Snow Process Modeling in the North American Land Data Assimilation System (NLDAS). Part I: Evaluation of Model Simulated Snow Cover Extent"
Justin Sheffield, Ming Pan, Eric F. Wood, Kenneth E. Mitchell, Paul R. Houser, John C. Schaake, Alan Robock, Dag Lohmann, Brian A. Cosgrove, Qingyun Duan, Lifeng Luo, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley, Bruce H. Ramsay

"Snow Process Modeling in the North American Land Data Assimilation System (NLDAS). Part II: Evaluation of Model Simulated Snow Water Equivalent"
Ming Pan, Justin Sheffield, Eric F. Wood, Kenneth E. Mitchell, Paul R. Houser, John C. Schaake, Alan Robock, Dag Lohmann, Brian A. Cosgrove, Qingyun Duan, Lifeng Luo, R. Wayne Higgins, Rachel T. Pinker, J. Dan Tarpley

"Surface Radiation Budgets in Support of the GEWEX Continental Scale International Project (GCIP) and the GEWEX Americas Prediction Project (GAPP), including the North American Land Data Assimilation System (NLDAS) Project."
Rachel T. Pinker, J. Dan Tarpley, Istvan Laszlo, Kenneth E. Mitchell, Paul R. Houser, Eric F. Wood, John C. Schaake, Alan Robock, Dag Lohmann, Brian A. Cosgrove, Justin Sheffield, Qingyun Duan, Lifeng Luo, R. Wayne Higgins

Non-NLDAS Publications

Berbery. E., Y. Luo, K. Mitchell, A. Betts, 2003: Eta model estimated land surface processes and the hydrological cycle of the Mississippi Basin, submitted to *J. Geophys. Res*.

Ek, M. B., K. E. Mitchell, Y. Lin, P. Grunmann, E. Rogers, G. Gayno, V. Koren, 2003: Implementation of the upgraded Noah land-surface model in the NCEP operational mesoscale Eta model, submitted to *J. Geophys. Res.*

Luo, L., A. Robock, and many Co-Authors, 2003: Effects of frozen soil on soil temperature, spring infiltration, and runoff: results from the PILPS 2(d) Experiment at Valdai, Russia, *J. Hydrometeor.*, in press.

Marshall, C., K. Crawford, K. Mitchell, and D. Stensrud, 2003: The impact of Land-Surface Physics in the Operational NCEP Eta Model on Simulating the Diurnal Cycle: Evaluation and Testing Using Oklahoma Mesonet Data, *Weather and Forecasting*, in press.

Roads, J., and many Co-authors, 2003: GCIP Water and Energy Budget Synthesis (WEBS), *J. Geophys. Res.*, in press.

Rodell, M., P. R. Houser, U. Jambor, J. Gottschalck, K. Mitchell, C.-J. Meng, K. Arsenault, B. Cosgrove, J. Radakovich, M. Bosilovich, J. K. Entin, J. P. Walker, D. Lohmann, and D. Toll, 2003: The Global Land Data Assimilation System, submitted to *Bull. Amer. Meteor. Soc.*

Syed, H., V. Lakshmi, E. Paleologos, D. Lohmann, and K. Mitchell, 2003: Analysis of spatial scales in land surface hydrological processs, submitted to *J. Geophys. Res.*